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ELECTROMYOGRAPHIC ANALYSIS OF THE BICEPS MUSCLE FOLLOWING STANDARD AIR DIVES USING FREQUENCY ANALYSIS: A FEASIBILITY STUDY

by

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and
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Bureau of Medicine and Surgery, Navy Department
Research Work Unit MR011.01-5003.01

Released by:

J. E. Stark, CAPT MC USN
COMMANDING OFFICER

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NAVAL SUBMARINE MEDICAL CENTER REPORT NO. 590

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SUMMARY PAGE

THE PROBLEM

To evaluate the feasibility of using the frequency analysis of the electromyogram to estimate adequacy of decompression following air dives.

FINDINGS

The findings are inconclusive in the present form, although the facts which prompted the investigation would seem to theoretically support further investigation. The results of the experiment show some frequency shift in selected individuals, but in an overall analysis, no definite statement can be made as far as relationship of the findings and a relationship to decompression adequacy is concerned.

APPLICATIONS

If frequency analysis of electromyograms could be refined sufficiently to show a constant shift relative to adequacy of decompression, it would simplify the diagnosis of decompression sickness markedly. Besides this, the onset of decompression sickness could be forestalled by extending the decompression until it was adequate. The method of frequency analysis of electromyograms has received some favorable response by clinicians and it appears to be adaptable for use on diving.

ADMINISTRATIVE INFORMATION

This investigation was conducted as a part of Bureau of Medicine and Surgery Independent Research Work Unit MR011.01-5003. The present report is the first on this work unit. It was approved for publication on 24 July 1969, and designated as Submarine Medical Research Laboratory Report No. 590.

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ABSTRACT

Frequency analysis of the electromyogram has been shown by clinical investigators to have some usefulness in diagnosing muscular and nerve disorders. The same methods employed following diving exposure were used to evaluate muscle frequency discharge. This was done with the idea of early diagnosis and evaluation of decompression sickness. The results of this experiment were such that no definite conclusion could be made although the feasibility of the approach could be evaluated as promising.

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INTRODUCTION

Decompression sickness, bends or caisson disease, is a rather frequent occurrence in divers and is usually ascribed to the formation of both intravascular and tissue fluid bubbles. Although this is the most readily apparent cause, Behnke[1] points out that as etiologic agents of dysbarism, bone marrow, fat emboli, tissue product breakdown and edema must be considered. There is also strong evidence to suggest lipids may play an important role[2].

Involved also is the effect of hyperbarism on individual cells. Doebbler et al[3] was able to demonstrate a reduced rate of growth in cultures of Hela cells to 65-90% of normal using between 10 and 70 atmospheres of inert gases such as nitrogen, helium, argon and krypton. He found that xenon and N_2O depressed growth rate to between 25% and 65% of normal in vitro at about 5 atmospheres. The logarithms of these pressures are linearly related to the logarithms of polarizabilities and the ionization potentials of the gases. Both parameters govern weak interaction forces (i.e., electrostatic, dispersion, and induction forces). He pointed out that, while many of the inert gases will form hydrates and clathrates under rigid conditions of temperature and pressure, their existence under physiologic conditions cannot be ruled out.

If present, they could affect the intermolecular interaction between the gas, the water and the biologic molecules of the muscles as well as other tissue moieties. This could exert changes in the dynamics of the cells and cell membranes and quite probably effect the polarization and depolarization of the muscles of the entire body.

As an entity related to this, the symptoms of nitrogen narcosis would seem to bear out a definite relationship between an effect at the cellular level and inert gas solution in the tissue which cannot be explained by the mechanical effect of increased pressure alone. Most theories on this phenomena equate nitrogen with the volatile anesthetic agents[4]. In addition to the suggested biochemical and biophysical effects, there is the mechanical effect of the gas evolving through the muscle tissue. Muscle tissue is homogeneous in the sense that each cell is composed of connective tissue sheaths, intracellular water proteins and collagen with blood and nerve supply. However, the architecture of the muscle cell seems to be such that the gas evolving would have some effect on the function of the muscle membranes and possibly some effect on the electrical potentials.

To further elaborate on this, a brief description of skeletal muscle follows. Typical skeletal muscle is composed of large numbers of elongated cells, each

cell enveloped by the sarcolemma made up of collagen fibrils embedded in colloid. Muscle cells (fibers) are bound together into bundles and enclosed in a connective tissue sheath, the perimysium. Another connective tissue, sheath epimysium, envelops the whole muscle[5].

The electrical activity detected in the electromyogram is produced for the most part by muscle cells and is called the muscle action potential and originates at the motor end plate. This action potential is triggered by the arrival of a nerve impulse at the neuromuscular junction. This potential then sweeps down the muscle fibers to initiate contraction[6].

Recently some electromyographers have advocated the use of frequency analysis to obtain a more quantified representation of the muscle action potentials[7,8]. In essence, this technique simply treats the detected muscle action potential as a summation of many simpler wave forms, each of which has a varying frequency and amplitude. A frequency analysis breaks a complex muscle action potential into the basic components occurring in preselected frequency bands[9].

In many diseases of muscle there is evidence of an increase in the number of high frequency discharges found on analysis of the EMG while the patient is alternately resting and working[9]. With these factors in mind, it was postulated that there would be a peak frequency band shift present in the muscle action potential of divers who were undergoing, or had recently undergone decompression. This initial study was made to determine whether or not such a phenomenon existed and whether it could be studied using the power density, frequency analysis of the EMG. If the degree of frequency change was sufficient, it might indicate the adequacy of decompression. No attempts were made to determine whether the cause of decompression sickness is related to bubble formation or biochemical effect.

METHODS

Eleven subjects volunteered to participate in the following experimental procedure. All subjects except one were active duty military personnel and one was a female. All subjects had successfully passed the fifty pound pressure test, oxygen tolerance test and diving physical examination in accordance with U.S. Navy diving physical requirements. The subjects ranged in age from 22 to 38 years.

The EMG method used was that of Davis[10] with surface electrodes of silver-silver chloride applied to the biceps muscle and positioned one inch above and below the midpoint of the muscle. The ground electrode was applied to the wrist. The muscle was lightly abraded with acetone and electrode paste was applied to insure a good contact.

For the actual recording, an Offner Type R Dynagraph with an EMG coupler 9852 was used and was set at a sensitivity of 5MV/cm. The Dynagraph was coupled to an Ampex tape recorder and the analog wave form recorded on magnetic tape at 3.75 inches per second. The recording

was monitored on a Tektronix oscilloscope RM561A.

After a baseline recording the following dives were made in a manrated hyperbaric chamber:

90 feet for 20 minutes ---	No decompression
90 feet for 25 minutes ---	No decompression
90 feet for 30 minutes ---	No decompression
120 feet for 30 minutes ---	With decompression according to Standard U.S. Navy Diving Table 1-5; Figure 1.

Within 20 minutes following each chamber dive each subject was placed in a sitting position and the electrodes applied to the right arm. A fifteen pound weight attached to a short belt was held in the right hand. On audible signal, the subject lifted the weight until the forearm was at a ninety degree angle with the upper arm. The weight was held for a fifteen second interval with two seconds of rest. The sequence was repeated four times at each recording.

These diving depths and times were chosen in order to provide a spectrum of conditions from well within the no decompression limit, 90/20, to one requiring some decompression, 120/30. In this way, it was hoped to show a gradual shift in peak EMG frequency as the length of time for the no decompression exposures increased and then a reverse shift as the decompression dive schedule was performed.

At least 24 hours elapsed between dives to prevent residual nitrogen effects. The results were analyzed using power density computer program supplied by Dr. D. Chaffin, Department of Industrial Engineering, University of Michigan. This program analyzed all the frequency discharges between 0 and 200 Hz. A Linc-8 computer was used for the actual analysis.

Frequency distribution of power density was also measured on a Kay Missilizer Audiospectrograph[11]. Figure 2 is a typical sonogram from this instrument. Section A is a graphic display of the power density for the entire measurement period, while section B is a detailed analysis of A, three points in time, as indicated by the arrows. In order to obtain a true power density spectrum over a 15-second time span, an average of multiple similar detailed analyses was made. The value of this method is limited by a relatively wide band width and excessive time required for data reduction.

In addition, tracings were made on EMG graph paper, at the same time utilizing the graphic system on the Offner Dynagraph at a paper speed of 10mm/sec.

RESULTS

The graphs of the results are shown. The frequency in cycles per second is shown on the abscissa while the

Table 1-5-U. S. Navy standard air decompression table.

DEPTH (ft)	BOTTOM TIME (mins)	TIME TO FIRST STOP	DECOMPRESSION STOPS 50	40	30	20	10	TOTAL ASCENT TIME	REPET. GROUP
40	200						0	0.7	*
	210	0.5					2	2.5	N
	230	0.5					7	7.5	N
	250	0.5					11	11.5	O
	270	0.5					15	15.5	O
	300	0.5					19	19.5	Z
50	100						0	0.8	*
	110	0.7					3	3.7	L
	120	0.7					5	5.7	M
	140	0.7					10	10.7	M
	160	0.7					21	21.7	N
	180	0.7					29	29.7	O
	200	0.7					35	35.7	O
	220	0.7					40	40.7	Z
	240	0.7					47	47.7	Z
60	60						0	1.0	*
	70	0.8					2	2.8	K
	80	0.8					7	7.8	L
	100	0.8					14	14.8	M
	120	0.8					26	26.8	N
	140	0.8					39	39.8	O
	160	0.8					48	48.8	Z
	180	0.8					56	56.8	Z
	200	0.7				1	69	70.7	Z
70	50						0	1.2	*
	60	1.0					8	9.0	K
	70	1.0					14	15.0	L
	80	1.0					18	19.0	M
	90	1.0					23	24.0	N
	100	1.0					33	34.0	N
	110	0.8				2	41	43.8	O
	120	0.8				4	47	51.8	O
	130	0.8				6	52	58.8	O
	140	0.8				8	56	64.8	Z
	150	0.8				9	61	70.8	Z
	160	0.8				13	72	85.8	Z
	170	0.8				19	79	98.8	Z
80	40						0	1.3	*
	50	1.2					10	11.2	K
	60	1.2					17	18.2	L
	70	1.2					23	24.2	M
	80	1.0				2	31	34.0	N
	90	1.0				7	39	47.0	N
	100	1.0				11	46	58.0	O
	110	1.0				13	53	67.0	O
	120	1.0				17	56	74.0	Z
	130	1.0				19	63	83.0	Z
	140	1.0				26	69	96.0	Z
	150	1.0				32	77	110.0	Z
90	30						0	1.5	*
	40	1.3					7	8.3	J
	50	1.3					18	19.3	L
	60	1.3					25	26.3	M
	70	1.2				7	30	38.2	N
	80	1.2				13	40	54.2	N
	90	1.2				18	48	67.2	O
	100	1.2				21	54	76.2	Z
	110	1.2				24	61	86.2	Z
	120	1.2				32	68	101.2	Z
	130	1.0			5	36	74	116.0	Z
100	25						0	1.7	*
	30	1.5					3	4.5	I
	40	1.5					15	16.5	K
	50	1.3				2	24	27.3	L
	60	1.3				9	28	38.3	N
	70	1.3				17	39	57.3	O
	80	1.5				28	43	72.5	O
	90	1.2			3	23	57	84.2	Z
	100	1.2			7	23	66	97.2	Z
	110	1.2			10	34	72	117.2	Z
	120	1.2			12	41	78	132.2	Z
110	20						0	1.8	*
	25	1.7					3	4.7	H
	30	1.7					7	8.7	J
	40	1.5				2	21	24.5	L
	50	1.5				8	26	35.5	M
	60	1.5				18	36	55.5	N
	70	1.3			1	23	48	73.3	O
	80	1.3			7	23	57	88.3	Z
	90	1.3			12	30	64	107.3	Z
	100	1.3			15	37	72	125.3	Z
120	15						0	2.0	*
	20	1.8					2	3.8	H
	25	1.8					6	7.8	I
	30	1.8					14	15.8	J
	40	1.7				5	25	31.7	L
	50	1.7				15	31	47.7	N
	60	1.5			2	22	45	70.5	O
	70	1.5			9	23	55	88.5	O
	80	1.5			15	27	63	106.5	Z
	90	1.5			19	37	74	131.5	Z
	100	1.5			23	45	80	149.5	Z
130	10						0	2.2	*
	15	2.0					1	3.0	F
	20	2.0					4	6.0	H
	25	2.0					10	12.0	J
	30	1.8				3	18	22.8	M
	40	1.8				10	25	36.8	N
	50	1.7			3	21	37	62.7	O
	60	1.7			9	23	52	86.7	Z
	70	1.7			16	24	61	102.7	Z
	80	1.5		3	19	35	72	130.5	Z
	90	1.5		8	19	45	80	153.5	Z
140	10						0	2.3	*
	15	2.2					2	4.2	G
	20	2.2					6	8.2	I
	25	2.0				2	14	18.0	J
	30	2.0				5	21	28.0	K
	40	1.8			2	16	26	45.8	N
	50	1.8			6	24	44	75.8	O
	60	1.8			16	23	56	96.8	Z
	70	1.7		4	19	32	68	124.7	Z
	80	1.7		10	23	41	79	154.7	Z
150	5						0	2.5	C
	10	2.3					1	3.3	E
	15	2.3					3	5.3	G
	20	2.2				2	7	11.2	H
	25	2.2				4	17	23.2	K
	30	2.2				8	24	34.2	L
	40	2.0			5	19	33	59.0	N
	50	2.0			12	23	51	88.0	O
	60	1.8		3	19	26	62	111.8	Z
	70	1.8		11	19	39	75	145.8	Z
	80	1.7	1	17	19	50	84	172.7	Z
160	5						0	2.7	D
	10	2.5					1	3.5	F
	15	2.5				1	4	7.5	H
	20	2.3				3	11	16.3	J
	25	2.3				7	20	29.3	K
	30	2.2			2	11	25	40.2	M
	40	2.2			7	23	39	71.2	N
	50	2.0		2	16	23	55	98.0	Z
	60	2.0		9	19	33	69	132.0	Z
	70	1.8	1	17	22	44	80	165.8	Z
170	5						0	2.8	D
	10	2.7					2	4.7	F
	15	2.5				2	5	9.5	H
	20	2.5				4	15	21.5	J
	25	2.3			2	7	23	34.3	L
	30	2.3			4	13	26	45.3	M
	40	2.2		1	10	23	45	81.2	O
	50	2.2		5	18	23	61	109.2	Z
	60	2.0	2	16	22	37	74	152.0	Z
	70	2.0	8	17	19	51	86	183.0	Z
180	5						0	3.0	D
	10	2.8					3	5.8	F
	15	2.7				3	6	11.7	I
	20	2.5			1	5	17	25.5	K
	25	2.5			3	10	24	39.5	L
	30	2.5			6	17	27	52.5	N
	40	2.3		3	14	23	50	92.3	O
	50	2.2	2	9	19	30	65	127.2	Z
	60	2.2	5	16	19	44	81	167.2	Z
190	5						0	3.2	D
	10	2.8				1	3	6.8	G
	15	2.8				4	7	13.8	I
	20	2.7			2	6	20	30.7	K
	25	2.7			5	11	25	43.7	M
	30	2.5		1	8	19	32	62.5	N
	40	2.5		8	14	23	55	102.5	O
	50	2.3	4	13	22	33	72	146.3	Z
	60	2.3	10	17	19	50	84	182.3	Z

*See table 1-6 for repetitive groups in "no decompression" dives.

Fig. 1. Navy Standard Air Decompression Table 1–5.

percentage of frequencies in each band between 0 and 200 is on the ordinate. It is graphed in such a fashion that on reaching 200 cycles per second 100% of the frequency discharge is included. In reviewing the graphs, no constant shift can be seen. Although there are shifts of a rather insignificant nature, no real pattern can be derived from this. The sonagram analysis failed to differ with the computer analysis and so is not included in the results. This system is much more difficult to work with due to the randomness in choosing

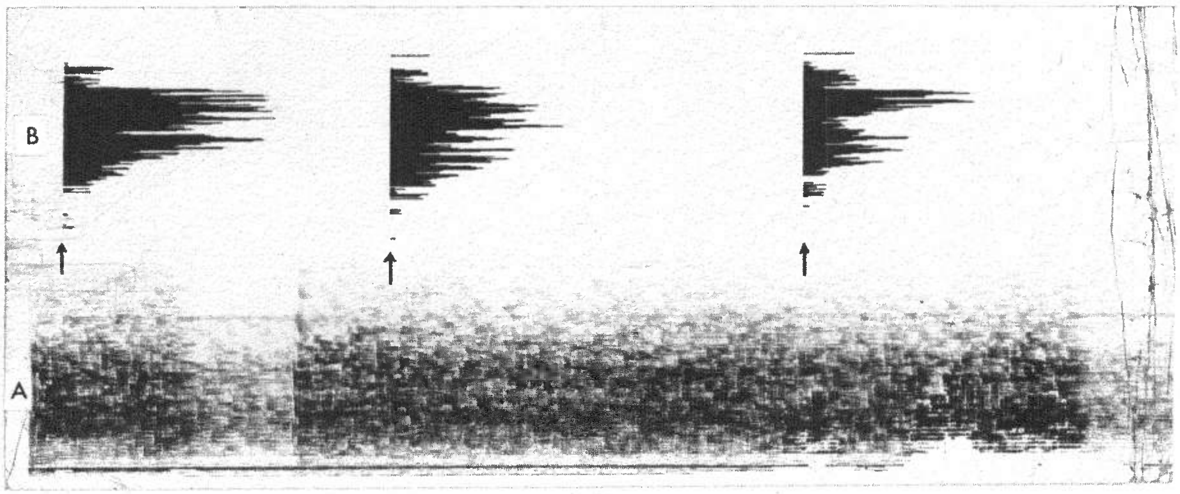


Fig. 2. A five second Kay Missilizer Audiospectrogram of an electromyogram following a 90 foot dive for 25 minutes.

an area of the recording from which to make an analysis.

Analysis of the EMG tracings showed a constant decrease in amplitude during each test, including the control, as the subject reached the fourth lift of the weight. The difference between the amplitude change in the pre-dive control tracings and the post-dive tracings was not constant and in many subjects not significant.

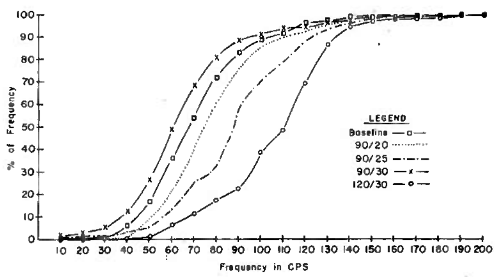
It is interesting that the lone female subject showed an overall shift to the high frequencies in the area of 140-160 cps at the 60% level as shown on graph number 3.

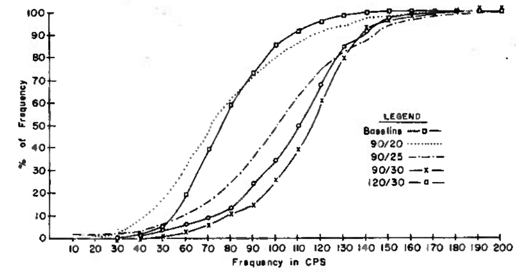
Of the three people who had a history of decompression sickness not related to the present experiment, two of them (graphs number 1 and 2) had a significant shift toward higher frequencies compared to the baseline. Both of these subjects were in their middle thirties. The other subject, in the middle twenties in age, showed no such shift. As a group within an age group this is significant. It is worth noting also that the younger subject (graph 4) had much less severe bends and that he responded rapidly to U.S. Navy treatment table 5, while the two older men required more extensive treatment.

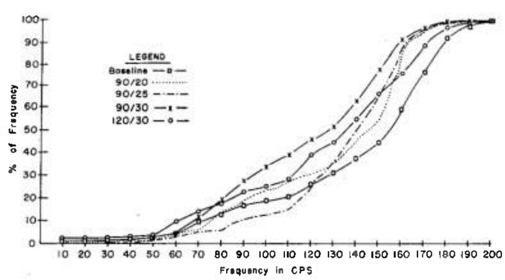
DISCUSSION

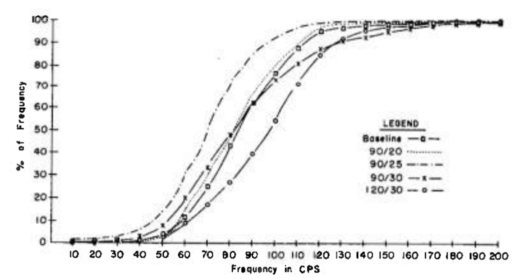
It was thought at the initiation of the study that there would be definite shifts to either the high frequencies or low frequencies in the EMG that would correlate in a mathematical fashion with the amount of nitrogen evolving from the muscle. If this was so, it might be possible to predict the adequacy of decompression of a diver before surfacing and prevent decompression sickness before it started.

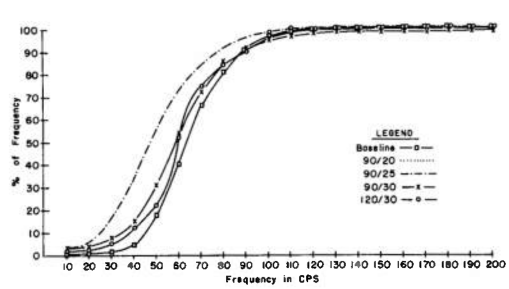
Although the results of the investigation fail to show a shift of significant quantity, it must be pointed out that the

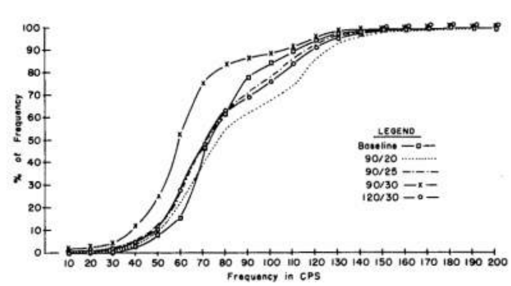

% of Frequency
Frequency in CPS
LEGEND
Baseline
90/20
90/25
90/30
120/30

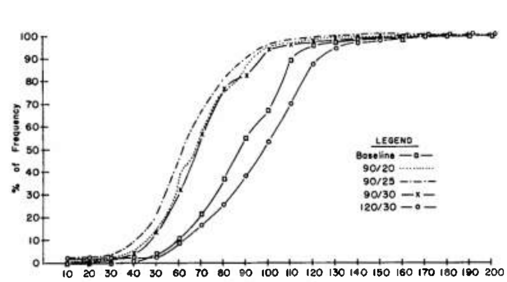

% of Frequency
Frequency in CPS
LEGEND
Baseline
90/20
90/25
90/30
120/30

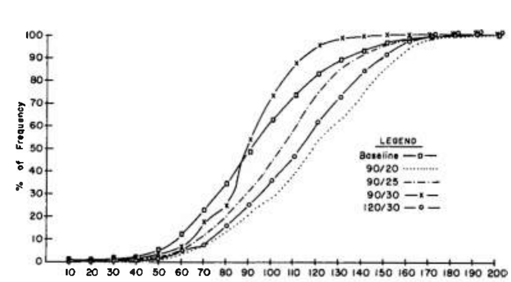

% of Frequency
Frequency in CPS
LEGEND
Baseline
90/20
90/25
90/30
120/30

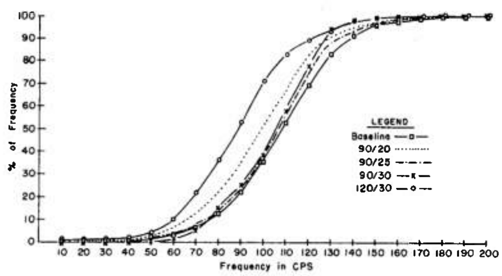

% of Frequency
Frequency in CPS
LEGEND
Baseline
90/20
90/25
90/30
120/30

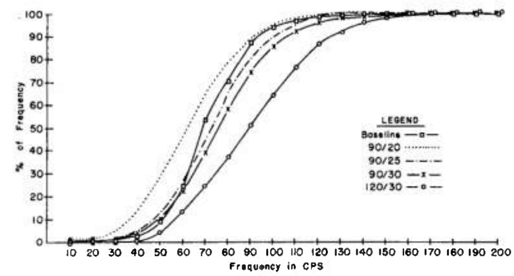

% of Frequency
Frequency in CPS
LEGEND
Baseline
90/20
90/25
90/30
120/30

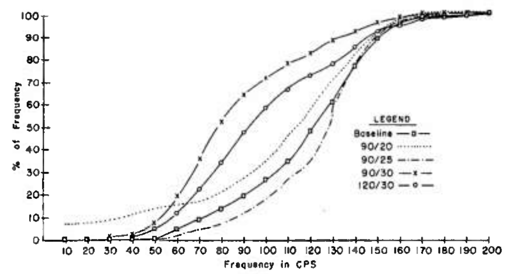

% of Frequency
Frequency in CPS
LEGEND
Baseline
90/20
90/25
90/30
120/30


% of Frequency
Frequency in CPS
LEGEND
Baseline
90/20
90/25
90/30
120/30


% of Frequency
Frequency in CPS
LEGEND
Baseline
90/20
90/25
90/30
120/30







study was limited by the computer program to the small area between 0 and 200 cps and that this in no way exhausts the complete range of frequencies. In a similar vein, the method used to graphically represent this particular study could be inadequate in terms of the overall picture. The graphic analysis was limited by the constraint of the computer program and filtering system used as far as can be determined. A repeat study with emphasis on control of amplification so that a histogram approach using the value from each frequency band could be used.

The approach using the sonogram is extremely time consuming and it is limited to taking a small cross section of the total recording taken at random. In this way, the area chosen would be likely to show invalid data unless a large population group were involved and statistical methods used.

The graphic tracings are almost impossible to use as an index of frequency discharge and the amplitude changes involved can be very misleading. The inertia of the direct pen writer does not follow sine waves of frequency greater than 80 to 100 cps and so is not adequate for this purpose[12].

It is still thought that there are sufficient biochemical and physical phenomena occurring at the cellular level during decompression to cause some

change in the mechanisms of membrane polarization and muscular electrical activity that would be apparent in the frequency spectrum of the EMG. Further investigation could be easily justified.

The feasibility of using this system for research in the area has been demonstrated although the results of the experiment indicate the need for an extension of the experimental method.

SUMMARY

Eleven healthy subjects underwent a series of dives chosen to approach the limits of decompression in order to evaluate the effects of evolving nitrogen gas on the frequency discharge of skeletal muscle. The frequency discharges were recorded on magnetic tape and analyzed, using a computer program designed for this purpose in another study. The results were basically negative, in the sense that no consistent shift to higher or lower frequencies occurred. However, it is indicated that the concept is not disproved and the method is not invalidated. Further work is contemplated.

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13. ABSTRACT

Frequency analysis of the electromyogram has been shown by clinical investigators to have some usefulness in diagnosing muscular and nerve disorders. The same methods employed following diving exposure were used to evaluate muscle frequency discharge. This was done with the idea of early diagnosis and evaluation of decompression sickness. The results of this experiment were such that no definite conclusion could be made although the feasibility of the approach could be evaluated as promising.

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